GERMAN AIR FORCE TORNADO BEDDOWN
HOLLOMAN AIR FORCE BASE, NEW MEXICO

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ABSTRACT

“Sprecken sie Steckdosenish?”

“Do You Speak Receptacles?”

The German Air Force Tornado Beddown Project at Holloman Air Force Base, Alamogordo, New Mexico required 220/380V 50 Hz, 120/208V 400 Hz, and 28V DC power systems in addition to conventional United States 60 Hz systems. This manuscript describes the static inverter power sources, distribution methods and components, and the dozen different German receptacles that were specified and installed. Many problems were encountered and resolved during the first design and construction phase, and were used as lessons learned for the second design phase (second construction phase begins late this fiscal year).

INTRODUCTION

In early 1993, the design engineers at the Albuquerque District ventured into their first German Air Force Tornado Beddown Project design. This project included a Maintenance Hangar and Parking Hangar, each with support offices, workshops, and six aircraft bays. The preliminary design was based on infrastructure requirements set forth by the United States Air Force (USAF) and the German Air Force (GAF), in support of the GAF Tactical Training Command at Holloman Air Force Base (HAFB). The entire design team faced a special challenge in satisfying the GAF, a new, non-traditional Albuquerque District customer. The biggest challenge for the electrical engineers was the requirement for five different power distribution systems; 220/380V 50 Hz, 120/208V 400 Hz, 28V DC, conventional 277/480V 60 Hz, and conventional 120/208V 60 Hz.

The 60 Hz system was designed to serve lighting, standard mechanical loads, and general use outlets. Solid state frequency converters were employed for the 50 and 400 Hz systems, and power supplies were used for the DC system. These 50 Hz, 400 Hz, and

DC systems all required International Commission for Conformity, Certification of Electrical Equipment (CEE) form, “shrouded” type receptacles at the required end use outlet locations. These industrial receptacles are in accordance with standards set by the International Electrotechnical Commission (IEC) Publication IEC 309. The first phase requirements also called for 50 Hz “Schuko” type duplex convenience outlets (standard European general use outlets) throughout the facilities. As can be imagined, some walls in these buildings were virtually covered with electrical outlets. Standard distribution practices were adhered to in all cases, derating and using non-magnetic conduit for the 400 Hz system, and specifying DC rated equipment and components for the DC system.

By the end of 1996, the GAF had occupied the facilities constructed under the first phase, and most of the electrical problems encountered had been addressed. Some of these problems included; electrical room overheating due to inadequate space and ventilation, system down-time due to the use of non-redundant frequency converters, changing GAF requirements, and receptacle mounting difficulties, to name a few. The problems stemmed from designer inexperience with the various systems, GAF oversight in the original requirements, and the inability to enforce electrical construction quality assurance (QA) recommendations because of schedule concerns. At the time of construction, the Albuquerque District had only one electrical engineer as full time construction QA inspector. His duties in supporting the entire District allowed only weekly visits to the GAF construction sites. Ordinarily, an on site, full time COE electrical engineer as QA inspector is not required, but this project consisted of unique electrical systems that demanded more attention. The second construction phase is scheduled to begin in late FY98, and will consist of a second maintenance hangar, three additional parking hangars, and several other support facilities. The second design phase has developed through lessons learned during construction and feedback from GAF personnel in the existing facilities. The second construction phase contract administration plan includes the requirement for a full time COE electrical engineer on site as QA inspector in addition to the general contractor’s full time electrical quality control personnel.

GERMAN AIR FORCE ELECTRICAL POWER SYSTEMS

SYSTEM DESCRIPTIONS

220/380V 50 Hz System

For the 50 Hz power system, two power source options were proposed to the USAF and GAF. The first proposal, in anticipation of the second phase and the completed GAF Tactical Training Command, involved constructing a small, natural gas powered, 50 Hz generating plant. The power would then be distributed through a network of medium voltage underground power lines and 50 Hz transformers, paralleling the 60 Hz system. The USAF and GAF preferred the second proposal; the use of individual frequency converters serving each facility.

120/208V 400 Hz System

The international aviation industry developed 400 Hz aircraft power systems in the 1960's to reduce the size and weight of electrical components.[1] The system is now a power system requirement in aircraft support facilities worldwide. The loads associated with this system in military installations are usually concentrated in hangars and maintenance shops (inside aircraft support facilities). For large airports, elaborate distribution systems served by central ground power generating stations are used, providing 400 Hz power to each airplane terminal.[2] But for military installations with aircraft support facilities, the smaller 400 Hz system loads are usually powered by individual frequency converters.

28V DC System

Direct Current systems are typically served by DC Power Supplies, located in close proximity to the end-use outlets, minimizing voltage drop. 28V DC, 16 and 32A receptacles are used by the GAF for certain test equipment. The systems were designed to serve the connected loads at 100% of the receptacle ratings, because specific DC demand information was not available. The first design phase called for three standard, off the shelf, 1200W units to be placed in a single enclosure with the outputs connected in parallel (Figure 1). These 3600W Power Supplies were located throughout the facilities close to their loads, minimizing the lengths of branch circuit wiring. The Power Supplies provided in the first phase are working well, so a similar design has been implemented for the second phase.

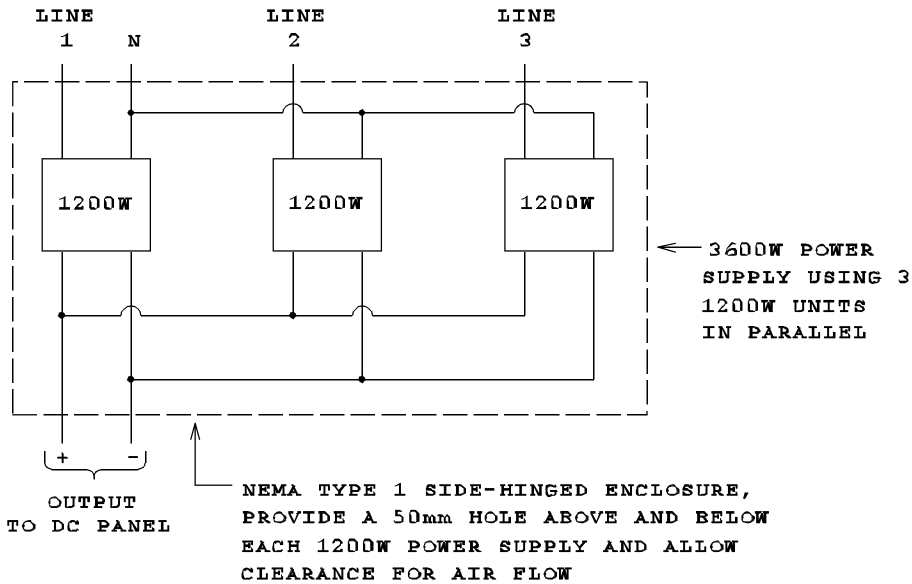

FIGURE 1 - DC POWER SUPPLY

50 AND 400 HERTZ FREQUENCY CONVERTERS

Frequency Conversion Methods

Two frequency conversion methods are commercially available, each with several advantages and disadvantages. The traditional method is by rotary type frequency converters.[3] The rotary converter is essentially an electrically powered motor-generator that requires periodic bearing maintenance and lubrication to ensure continuous operation. The Aircraft Ground Equipment (AGE) shops and Base Civil Engineering (BCE) maintenance shops at HAFB are not staffed nor equipped to service this type of equipment. In this era of Base closures and Department of Defense budget and personnel reductions, the use of high maintenance equipment is avoided. This type of converter is rather noisy, due to the fact that 400 Hz is within the audible range and because of mechanical vibration (even though design improvements have alleviated this problem over the years). Output frequency instability is also a problem.[4] Because of their moving parts, rotary converters suffer considerable heat losses, and do not respond well to large step load increases. However, an advantage of the rotary converter is complete electrical line isolation. A cursory investigation revealed available sizes required several in parallel, to achieve the total kVA needed for the largest GAF system.

The newest method is by solid state frequency converters (generally referred to as static inverters). The static inverter is low maintenance and employs two devices in series; an AC-DC converter and a DC-AC converter. The major disadvantage of the inverter is that it is not electrically isolated and can place considerable electrical noise back on the source line. This can be minimized by limiting the input and output total harmonic distortion. Static inverters are very efficient (92% efficiency specified) and respond instantly to step load increases. Static inverters generate some acoustical noise, but this is rarely a problem, except when there is a loose piece of laminant or component. Maximum generated noise levels should always be specified. Static inverters are available in single unit sizes up to 1000 kVA, and possibly larger, depending on the manufacturer. The industry is steadily moving toward the use of more solid state electrical devices. The advantages and disadvantages of each inverter type were discussed, and it was agreed to employ static inverters throughout the GAF facilities for both the 50 and 400 Hz systems.

Inverter Sizing and Specifications

In both design phases, the inverters were sized to provide for both known and future loads in all the GAF facilities requiring 400 and 50 Hz power. The connected loads were derated by a demand or “coincidence” factor provided by the GAF, and then summed to reach a total demand load. This value was then increased for future loads and used to select the next standard size inverter (some manufacturers will custom build most any size). For the first Parking Hangar, a 150 kVA 60 to 400 Hz, and a 250 kVA 60 to 50 Hz frequency converter were required. For the first Maintenance Hangar, a 187.5 kVA 60 to 400 Hz, and a 1000 kVA 60 to 50 Hz frequency converter were required.

Presently a COE Guide Specification for Frequency Converters does not exist. Specifications are expensive to develop and maintain. There is not enough demand within the COE for this type of specification. United States Naval Facilities (USNF) maintains two frequency converter specifications, one for solid state converters (16268) and one for rotary converters (16236). The USNF guide Specification Section 16268, “50 and 400 Hertz Solid State Frequency Converters”, was acquired and edited for use in the GAF projects. The edited specification follows standard COE format and is available upon request by contacting the author. A 277/480V, 3 phase, 4 wire, grounded, 60 Hz, input was specified for the static inverters. The inverters were fed directly from the facility Main Distribution Panel (MDP). The specification required wiring for all 400 Hz circuits to be installed in non-magnetic conduit; aluminum or PVC.

DC, 50, AND 400 HERTZ RECEPTACLES

CEE Form Receptacles

The receptacles other than general 60 Hz required by the GAF in workshops consisted of 50 Hz, 400 Hz, and Direct Current CEE form, "shrouded" type. CEE form receptacles in Germany are round plugs and sockets with rated voltages up to 750 V and rated currents up to 200 A, primarily for industrial, commercial, and agricultural purposes. Any plug with rated voltage above 50 V has a ground "earth" contact. The sockets typically have a key-way and plugs have a nose or key that engage when inserted. The ground contact on both the socket and key-way are specifically located, designated by a clock face position (Figure 2).[5]

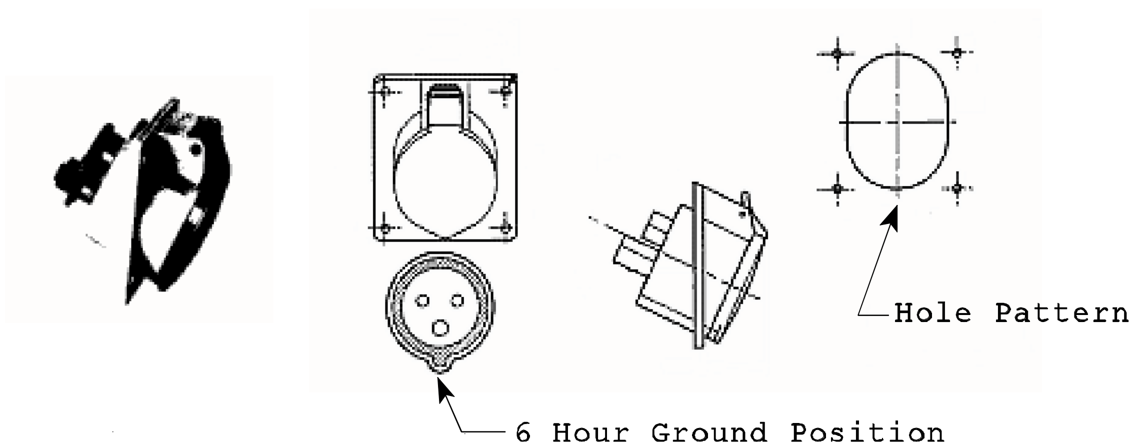

FIGURE 2 –CEE FORM TYPE "A" RECEPTACLE

The first phase projects called for a dozen different types of CEE receptacles as shown in Table 1. After the GAF re-evaluated their special power needs prior to the second design phase, the number of different types of CEE receptacles was reduced to six.*

A paint shop was required in the second phase Maintenance Hangar, therefore all electrical equipment within this room had to be Class 1 Division 2 explosion proof. To comply with the National Electrical Code (NEC), the three CEE type receptacles installed in this room were specified as IEC Rated, Zone 2 (comparable to Class 1 Division 2 hazardous area) explosion proof, switched and interlocked receptacles.^

CEE FORM RECEPTACLE SCHEDULE							
Type	**Freq.**	**Poles**	**Voltage**	**Rating**	**Number of Phases**	**Ground Position**	**Number of Pins**
*^ A	50 Hz	P+N+E	220V	16A	1 Ph	6 Hr	3P
K	50 Hz	P+N+E	220V	32A	1 Ph	6 Hr	3P
*^ B	50 Hz	3P+N+E	220/380V	16A	3 Ph	6 Hr	5P
*^ C	50 Hz	3P+N+E	220/380V	32A	3 Ph	6 Hr	5P
D	50 Hz	3P+N+E	220/380V	63A	3 Ph	6 Hr	5P
* E	50 Hz	3P+N+E	220/380V	125A	3 Ph	6 Hr	5P
F	400 Hz	P+N+E	115V	16A	1 Ph	2 Hr	3P
* G	400 Hz	3P+N+E	115/200V	16A	3 Ph	2 Hr	5P
H	400 Hz	3P+N+E	115/200V	32A	3 Ph	2 Hr	5P
I	400 Hz	3P+N+E	115/200V	63A	3 Ph	2 Hr	5P
* X	DC	2P	28V	16	+/-	10 Hr	2P
Y	DC	2P	28V	32	+/-	10 Hr	2P

TABLE 1 - GAF RECEPTACLE TYPES

“Schuko” Duplex Receptacles

European 50 Hz “Schuko” type duplex receptacle outlets (Figure 3) were only required in the first phase projects, when the GAF anticipated bringing and using standard European appliances, including personal computers. These receptacles are standard two

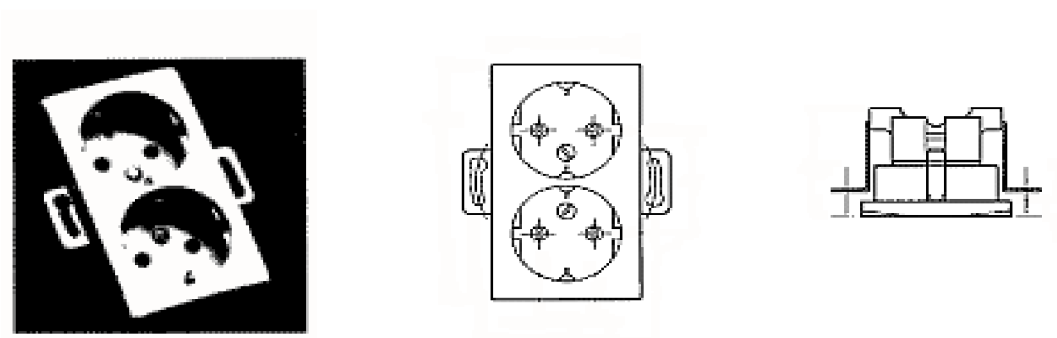

FIGURE 3 –“SCHUKO” TYPE DUPLEX RECEPTACLE

pole and ground pin receptacles using 50 Hz, 220 V single phase power. The term “Schuko” comes from the two German words “schutz”; meaning protection (against shock), and “kontakt”; that is, (electrical) contact. “Grounded Receptacle/Plug” would be an accurate translation.

Again, after the GAF re-evaluated their special power needs prior to the second design phase, they decided to procure personal computers and convenience appliances in the United States, thereby eliminating the need for “Schuko” type duplex receptacles.

Receptacle Manufacturers

Several companies manufacture CEE form receptacles. The supplier for the first GAF construction phase was Mennekes Electronics, Inc., whose products are made in Germany and are available in the United States. The electrical sub-contractor originally proposed installing receptacles manufactured in Brazil, made of inferior plastic material. CEE receptacles are only made with plastic materials and should be able to withstand industrial applications, made of impact resistant thermoplastic. Fortunately, the submittal reviewer was able to reject the use of Brazilian made receptacles, since their purchase and use would have violated the Buy American Act -- Construction Materials Under European Community and North American Free Trade Agreements, that is generally a contract clause.

DISTRIBUTION EQUIPMENT AND COMPONENTS

120/208V 400 Hz System

Two important considerations in the design of 400 Hz power distribution systems are due to the higher inductive reactance “X”, as expressed by the formula:

$$X = 2\pi fL$$

Where “f” is the frequency and “L” is the inductance. The first consideration is voltage drop. Since the inductive reactance is proportional to the frequency, 400 Hz voltage drop due to the increased impedance is almost seven times greater than in 60 Hz power systems.[6] For airport distribution systems, where long runs to terminals are necessary, line drop compensators (LDC) that consist of capacitors canceling out the inductive reactance are typically used. Voltage drop in 400 Hz systems should be kept below eight percent.[7] To achieve this in the GAF projects, voltage drop for the 400 Hz systems was calculated using a 60 Hz system model, restricted to within one percent.

The second consideration in the design of 400 Hz power distribution systems is feeder and branch circuit conduit material. Non-magnetic raceways must be used in 400 Hz systems. If not, the presence of magnetic materials elevates the flux density around the conductors and further increases the inductance. If magnetic conduit is used in 400 Hz systems, an additional 25 to 30 percent voltage drop can be expected.[8]

Emergency Cutoff Switches

Emergency Cutoff Switching is an important electrical requirement for the GAF. Selected workshops and each aircraft hangar bay in the GAF facilities required cutoff switches that turn off power to all receptacles within the area. This requirement posed a special challenge, given safety considerations. Isolating the different power systems and the control circuit from each other made the switching requirement difficult to implement. The first option explored was to use a set of contactors located within separate enclosures, all operated by the emergency switch. This option would have required custom enclosures for the contactors and would have needlessly cluttered the areas affected with the enclosures and additional conduit. The second, and exercised, option was to simply use shunt trip breakers for all branch circuits affected (Figure 4). As stated in the schematic, a

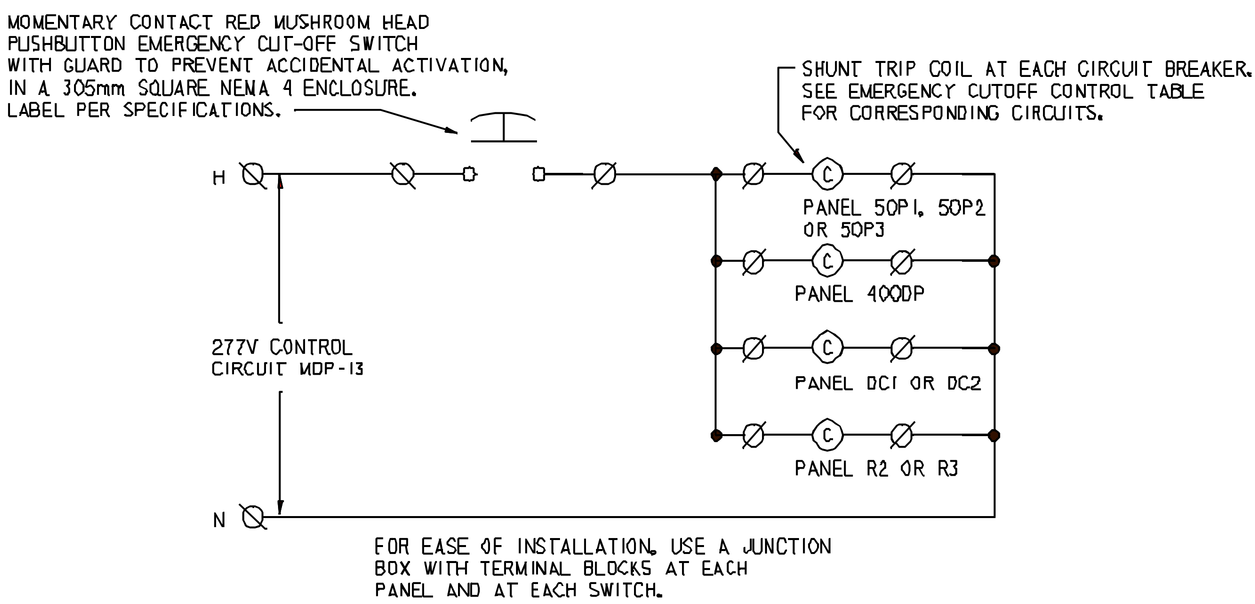

FIGURE 4 - EMERGENCY CUTOFF CONTROL SCHEMATIC

control table showing corresponding circuits for each area was developed and included in the designs. Most shunt trip circuit breakers require an additional breaker space and were shown as such in the panel schedules. For maintenance safety, the control circuit was taken from the main distribution panel (MDP), from where all systems are fed.

Electrical Distribution Terminals

The GAF uses 50 Hz, 400 Hz, and DC power at every aircraft bay in their hangars, and therefore required these power systems be distributed to each. As in the workshops, CEE form receptacles were needed. These receptacles come pre-mounted on electrical distribution terminals (EDT) procured in Germany and provided by the GAF. The EDT's are either wall mounted, or mounted on a swinging structural arm designed to extend the reach of connected equipment. In both cases, the design requirements called for routing the branch circuit wiring of each system to a junction box enclosure near the EDT location, and then making the proper connections.

LESSONS LEARNED

FREQUENCY CONVERTERS

System Reliability

Early on in the first design phase, manufacturers indicated that the preferred way of configuring the larger frequency converters was to connect at least two smaller, standard units in parallel. This is due to the limited availability of the larger power solid state components. The specification indicated system operating parameters when two or more converters are installed in parallel. At the time of construction, the contractor received the lowest bid for the frequency converters from a manufacturer who insisted they could package each one as a single unit, even the 1000 kVA 60 to 50 Hz converter in the Maintenance Facility. The COE became concerned about reliability of the different systems, hoping to get paralleled units, but the converter specification did not require them. Without creating a change order, and increasing the cost of the systems dramatically, there was no way the COE could get the paralleled unit packages, and therefore, had to settle for a less reliable system. The construction and design engineers met with the manufacturer and inspected his facility. After discussing their capabilities with the Transatlantic Program Center, who had just completed acceptance tests on similar equipment, it was decided to accept the proposed units. The 1000 kVA unit was recognized to be the first manufactured unit of that size to not use paralleled components. Competing manufacturers predicted that it couldn't be done within specification.

Shortly after the Maintenance Hangar was occupied, the 1000 kVA 50 Hz inverter failed and rendered the GAF without their European power. This happened twice, first when a diode failed and was replaced under warranty, and then when an insulation breakdown occurred that took ten days to fix, again under warranty. The second design phase has taken steps to minimize the problem in the frequency converter specification by requiring paralleled units for redundancy. The systems will not be fully redundant, but will provide for a maximum loss of 50% capacity should one paralleled unit fail. The systems will consist of master and slave units, alternately sharing the load. Each unit will be independent, and may be replaced or repaired without interrupting the system.

An added advantage in using paralleled units is the reduction of total harmonic distortion (THD) produced by the system. As the load demand decreases below 50%, when two paralleled units are used, the slave unit goes off line, thereby reducing the THD. If more units are used, then the benefits are even greater. Specifying paralleled units also allows for simpler future expansion.

Converter Installation

Historically, the infamous Architect has left the Electrical Engineer no other alternative, but to locate electrical equipment in hallways, janitor’s closets, mechanical rooms, and other likely places within new facilities. The Maintenance Hangar in the first phase was no exception. Even though a dedicated electrical room was included in the design, it could have easily been mistaken for a closet. Estimating physical sizes of equipment to be used in a facility is difficult when there are at least three manufacturers who make that equipment. Even when choosing the largest, often there is a multitude of accessories that are not considered.

Discussion with manufacturers revealed no one in the industry could provide physical dimensions for the large 1000 kVA 50 Hz inverter to be used in the Maintenance Hangar, because none had ever manufactured one that size. The best estimate of physical dimensions came only from summing the dimensions of three 375 kVA units in parallel from one manufacturer, but this proved grossly inaccurate, mostly because the contractor purchased a single unit inverter from a different manufacturer. There was no room along any wall inside the electrical room to locate the inverter, therefore it had to be constructed as a freestanding unit, to be located in the middle of the electrical room. The single unit 1000 kVA 50 Hz inverter was so large that the double exterior doors in the electrical room had to be replaced, to provide installation clearance.

The excessive amount of heat generated by the equipment in the overcrowded electrical room could not be adequately dissipated. The ventilation system could not maintain the design ambient temperature, therefore a cooling system had to be installed. The simple exhaust fan provided in the original design was replaced by a sizeable evaporative cooler to pressurize the room. This forced waste heat (mostly produced by the static inverters) out of the room to the exterior of the building through ducts installed directly from the top of the unit.

Manufacturer's Warranty

Recently, the 400 Hz frequency converter in the phase one Parking Hangar was shutting down with an inaccurate overheating failure as indicated by the unit's diagnostics equipment. The one-year warranty, as specified, did not cover the repairs. Therefore, for the second design phase, a three-year parts and labor warranty has been specified.

RECEPTACLE MOUNTING

From early on in the first construction phase, the Contractor did not recognize the uniqueness of the GAF power systems. This was the case even though the specifications and drawings pointed to the need for specially fabricated plates for receptacle mounting, with holes drilled to match those on the metrically dimensioned receptacle flanges. Typically, CEE form receptacles are panel or surface mounted. In Germany, they are normally fed by exposed cabling or wire in exposed conduit. For these projects, exposed and surface mounted electrical installation was to be naturally avoided. After all, they were new facilities, where concealed conduit was desired, to achieve a clean installation. This in turn required conventional American back boxes with the receptacles mounted over custom plates. The Contractor was asked to submit mounting detail drawings and sample installations for approval, but he refused, claiming the contract did not require them. In the end, the receptacles were haphazardly installed. Some were so loose, they could be easily pulled off the wall.

Similarly, the "Schuko" receptacles were badly installed. The GAF's decision to not require "Schuko" type duplex receptacles for the second phase was a blessing for the electrical designers, given the mounting problems encountered during the first construction phase. Many receptacles had to be reinstalled and properly secured. Part of the problem was that the Contractor used sheet metal screws instead of machine screws with hex nuts to secure the receptacles to the custom plates. Receptacle mounting details have been developed during the second design phase to minimize the installation problems (Figure 5).

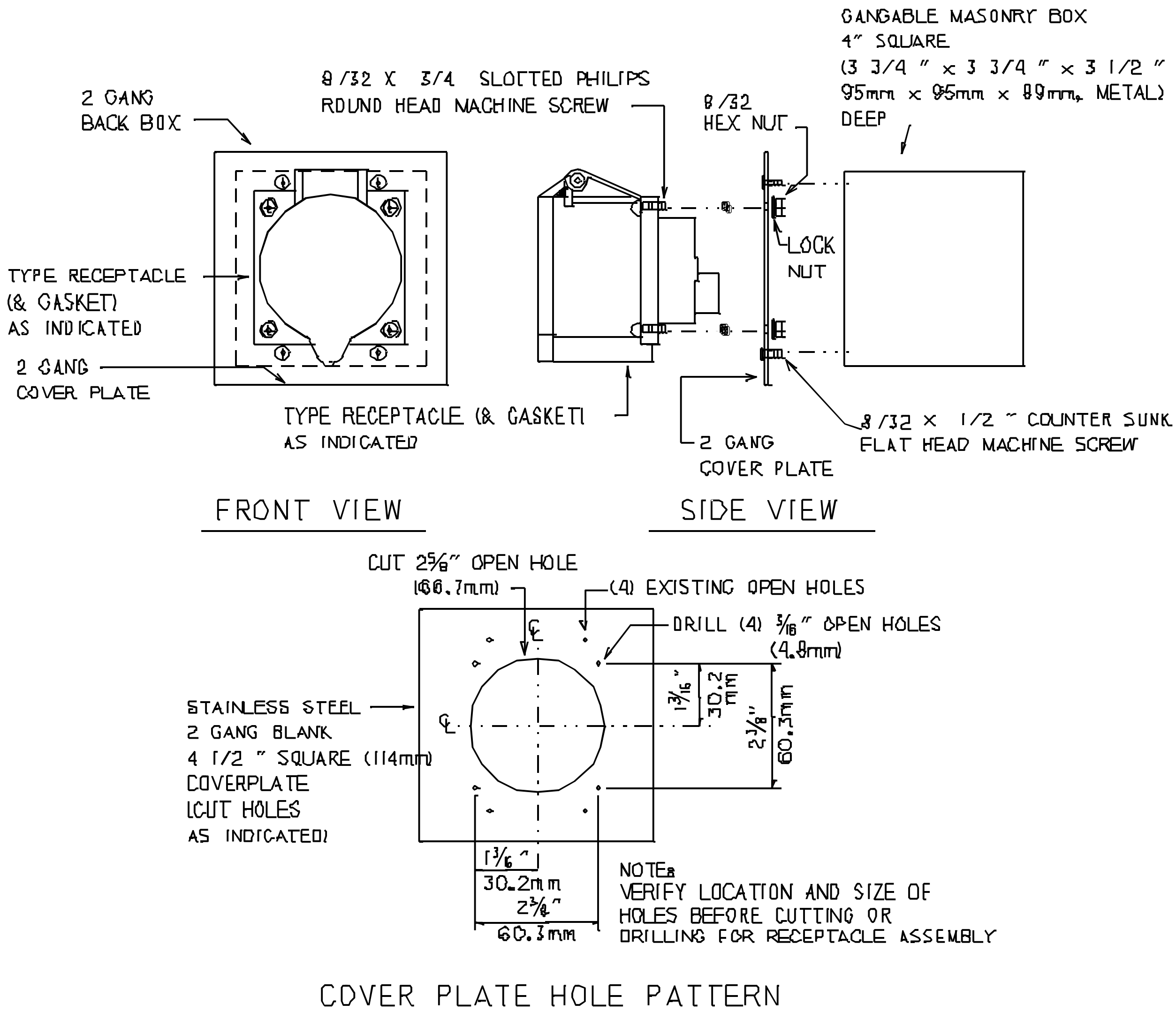

FIGURE 5 - TYPICAL CEE FORM RECEPTACLE MOUNTING DETAIL

The 125 Amp CEE form receptacle type “E” required a heavy duty installation (panel mounted) with a spacious enclosure due to the size of wire required (Figure 6).

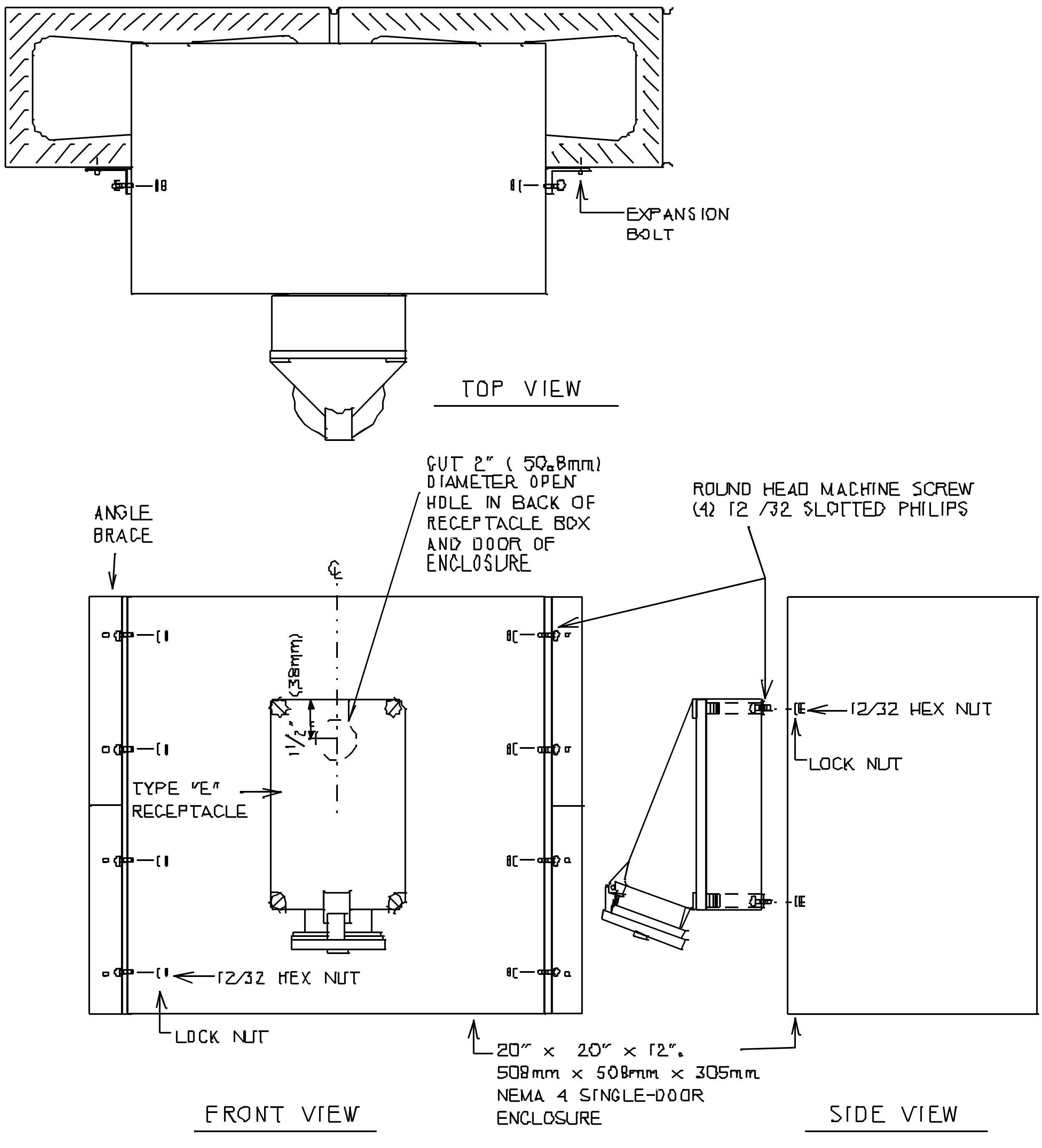

FIGURE 6 - TYPE "E" CEE FORM RECEPTACLE MOUNTING DETAIL

All GAF power system receptacles in the second construction phase are to be installed in CMU block walls, making installation that much more secure. The first phase facilities included receptacles mounted on gypsum board walls.

CONCLUSION

Now that the second GAF Tornado Beddown Project design phase has come to a close, much effort has been expended to ensure customer satisfaction. Lessons learned, feedback, and constant communication between all parties involved has resulted, we believe, in a quality design, to be followed by quality construction. The GAF has continued to look to the COE for solutions as they establish their training mission at HAFB. With the ensuing $100 Million, second construction phase completed in early 2000, the GAF will capably staff their Tactical Training Command from the current 200 to 1100 civilian and military personnel.

ACKNOWLEDGMENTS

Many people have been involved in the design and construction of the GAF projects at HAFB. Mr. William Wadsworth, Electrical Work Leader during the first design phase, developed the initial frequency converter specifications and coordinated the GAF design requirements. Toward the end of the first design phase, Mr. Wadsworth transferred to the District electrical QA position, and was directly involved in the construction of the first phase facilities. The author acknowledges the use of information provided by Mr. Wadsworth and Mr. John Tokar at USACE Headquarters, and thanks the Facilities Design Section and those in Construction for all their hard work in making the GAF Projects a success.

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